National Aeronautics and Space Administration
http://www.nasa.gov/
Explore. Discover. Understand.

The Einstein Probes

What is the mysterious energy pulling the Universe apart?
What happens to space, time, and matter at the edge of a black hole?
What powered the Big Bang?

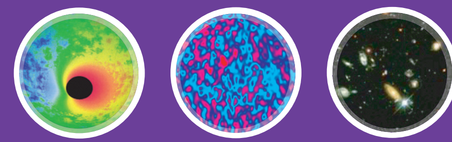
Einstein Probes are three competed missions that address focused science questions through scientist-led investigations. The three Einstein Probes, to be launched in the next decade, will each focus on a single question.

The Joint Dark Energy Mission

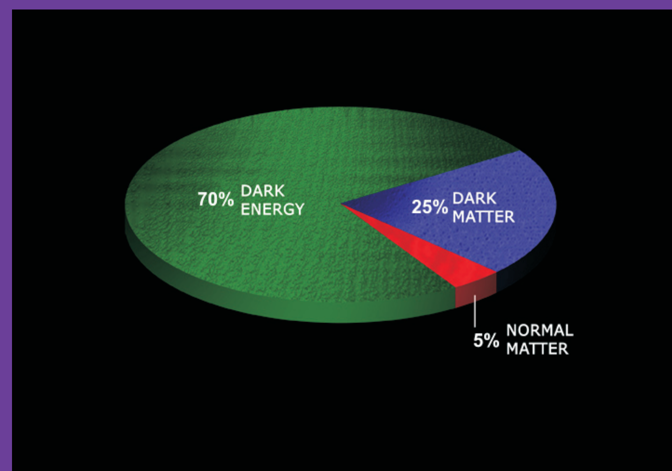
What is the mysterious energy pulling the Universe apart?

Dark energy is the name given to the unknown force that appears to be ripping the Universe apart. Not only is the Universe expanding, the rate of expansion is accelerating. We live in a runaway Universe, where the most distant galaxies are racing away from us at breakneck speed. Galaxies within our view today will eventually be forever beyond the horizon.

Dark energy is the biggest mystery in physics and astronomy. Although it comprises a whopping 70% of the Universe, we know very little about what it is. Scientists describe this as a force with negative pressure that permeates all of space. This property of negative pressure makes dark energy appear like a force acting in opposition to gravity. Dark energy's discovery—or, perhaps, its realization—came in 1998. Scientists at the time were measuring the Universe's expansion, set in motion by the Big Bang, to determine whether it would expand forever or eventually fall back in a big crunch. The revelation of a rapidly accelerating Universe was astonishing and has since been verified through four wholly independent measuring techniques.



"What is the mysterious energy pulling the Universe apart?" is a question that would not have been asked five years ago, before there was evidence that the Universe is being pulled apart. To understand this energy, we must measure the expansion of the Universe with high precision.



Dark energy comprises approximately 70% of the mass-energy of the Universe. The Joint Dark Energy Mission will accurately determine the amount of dark energy, and, most important, how it evolves with cosmic time. These measurements are crucial to constrain the nature of dark energy and ultimately may point the way to unite Einstein's theory of general relavitivy with quantum mechanics, going *Beyond Einstein*.

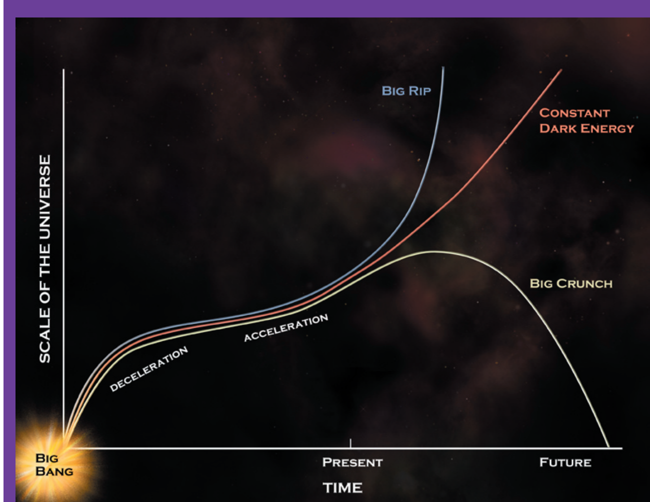
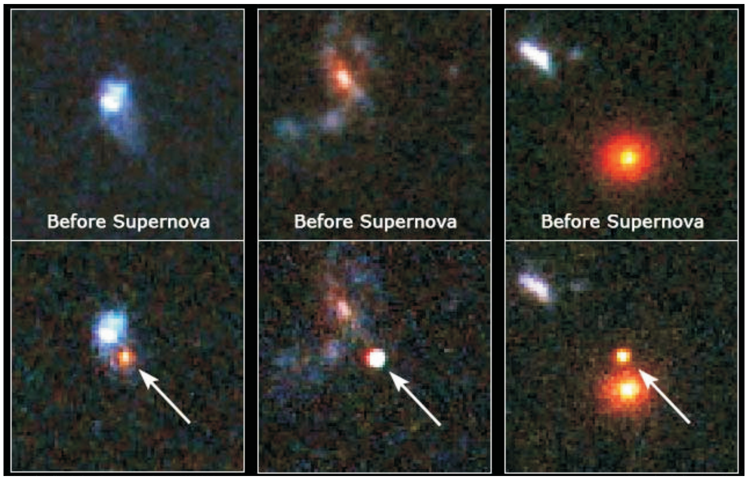


Image credit: NASA/CXC/M.Weiss

The fate of the Universe is uncertain, depending on the strength of dark energy.



These images from the Hubble Space Telescope show three of the most distant supernovae known. The stars exploded when the universe was approximately half of its current age. The light is just now arriving at Earth. Supernovae are so bright they can be seen far away and far back in time. This allows astronomers to trace the expansion rate of the Universe and to determine how it is affected by the repulsive push of dark energy, an unknown form of energy that pervaded space.

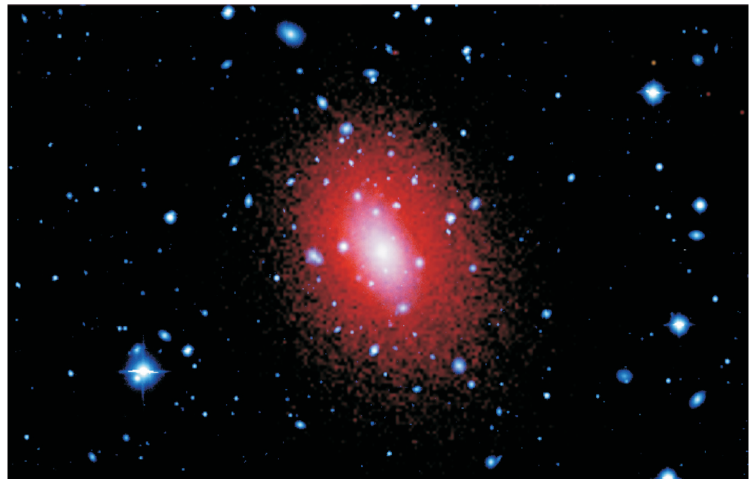
The question of dark energy is key to the Beyond Einstein initiative, for its discovery points to a fundamental problem with our two guiding theories of nature: general relativity and quantum mechanics. We must venture beyond Einstein's theories in order to understand dark energy. A joint dark energy mission, an interagency partnership between NASA and the Department of Energy, will provide the first, significant clues to the nature of dark energy by precisely determining how much there is and how it evolves with the age of the Universe.

Dark energy, the early days…

Because Einstein originally thought the Universe was static, he needed a counterbalance to keep gravity from causing the Universe to implode. He conjectured that even the emptiest possible space, devoid of matter and radiation, might still have energy, which he called a "cosmological constant." But when Edwin Hubble discovered the expansion of the Universe, Einstein rejected his own idea, calling it his greatest blunder.

Einstein may have been wrong about being wrong. The expansion of the Universe from the Big Bang appears indeed to have slowed down as expected due to gravity… but that was several billion years ago. Something—this dark energy—then became the dominant force, and the Universe has been accelerating ever since.

An interagency space-based dark energy mission will measure the expansion over the history of the Universe accurately enough to learn whether this energy is a constant property of empty space, as Einstein conjectured, or whether it changes over time and shows signs of the richer structure that is predicted in modern "unification" theories. (Unification refers to the goal of finding a single theory to describe nature, as opposed to our two guiding theories, general relativity and quantum mechanics, which are overwhelmingly useful yet oddly incompatible.)



The structure of galaxy clusters, such as Abell 2029 (above), is a result of a tug of war between gravity and dark energy.

Measuring the invisible…

There are several ways to measure the expansion of the Universe, such as using star explosions as mileage markers or watching the evolution of galaxy clusters, which are like large groups of islands. Dark energy was discovered through an in-depth study of a certain kind of star explosion called a Type Ia supernova, often described as a "standard candle" because each Type Ia supernova releases the same amount of energy, like light bulbs of similar wattage.

By knowing the intrinsic brightness and by observing any given Type Ia supernova's apparent brightness, scientists can determine distances to these explosions and thus map out the Universe using each explosion as a mileage marker. A dedicated Type Ia supernova finder could locate more of these mileage markers to provide a better sense of the effect of dark energy over time.

The study of galaxy clusters, the largest structures in the Universe, enables scientists to view an ecosystem of galaxies. Most of the mass in clusters is between the galaxies in the form of hot, thin gas that radiates in X-ray light, far more energetic than what optical telescopes detect. A dedicated galaxy cluster observatory could monitor the flow of cluster gas and watch how clusters evolve. Their structure is chiseled by the countering forces of gravity and dark energy.

These are just two ideas for the Einstein dark energy probe. A scientific competition will determine how to best approach the dark energy mystery.

Einstein Black Hole Finder

How do black holes form and grow?

A black hole is a point in space of infinite density from which nothing, not even light, can escape. Black holes warp space, bend light, and slow time. This is gravity at its extreme. Such objects were a mere fanciful notion for several hundred years, oddities that could exist in theory based on Isaac Newton's law of gravity. Albert Einstein's theory of gravity, called general relativity, gave further credence to their existence. The first observational proof would need to wait for seven more decades.

Although invisible by definition, black holes create quite visible commotion around them. Quasars, for example, are among the brightest objects in the Universe; and the engine powering this terrific outpouring of light in a massive black hole. Matter falling towards a black hole, attracted by gravity, heats to great temperatures and shines brightly. As much as half of the light in the Universe might be produced by black holes pulling in matter, a phenomenon called accretion.

Black holes are prodigious producers of X-ray light, far more energetic than the optical light our eyes can detect. An X-ray satellite discovered the first black hole candidate, called Cygnus X-1, in the 1970s. Since then data from X-ray satellites, such as NASA's Chandra X-ray Observatory and the European Space Agencies XMM-Newton, reveal that black holes are everywhere and come in a variety of sizes. Our Milky Way galaxy has millions of small, stellar black holes dotted throughout its spiral arms and a single, massive black hole at its core.

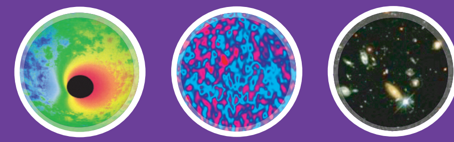
Riding on the rim of a black hole…

More exciting, we have observed how space itself appears to be dragged by a black hole, like a bowling ball spinning in molasses, as Einstein's equations predict. We also see evidence of time slowing and of matter whizzing around a black hole at near light speed and shooting off in collimated jets. Radio and optical telescopes and X-ray and gamma-ray satellites all have provided convincing evidence for black holes.

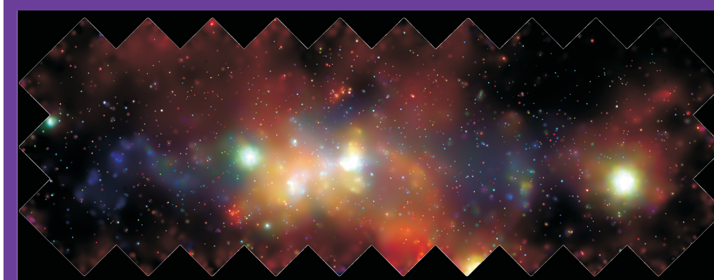
Black holes are laboratories for extreme physics; and it is here that we plan to put Einstein's equations to the ultimate test with a black hole finder probe working in concert with the two Beyond Einstein flagship missions, LISA and Constellation-X.

What happens to matter and energy as it moves closer to a black hole and crosses the event horizon, the theoretical border from which nothing can escape? Does time really come to a standstill? Will we see a breakdown in general relativity in the environment of extreme gravity? General relativity makes specific predictions about matter and energy close to a black hole. If, upon close scrutiny, we see the slightest deviation between theory and observation, we will understand limitations in Einstein's equations.

The black hole finder probe, as the name implies, will locate new black holes, conduct a true census, determine different classes of black holes, and reveal their role in shaping galaxies. Scientists say that most black holes are in hiding, protected behind a shroud of the dust and gas kicked up the black holes. Only the most penetrating forms of light, such as higher-energy or "hard" X rays, can slice through the shroud. The black hole finder probe will likely have high-energy X-ray detectors with sensitivity greater than any satellite in operation today.



"How do black holes form and grow?" Scientists have identified two main classes of black holes: smaller, stellar-sized black holes that form from the collapse of massive stars; and supermassive black holes in the core of most galaxies. The latter can contain the mass of millions to billions of suns and grow by swallowing stars and gas that venture too close. Black holes are the utmost expression of gravity, regions so dense that not even light can escape their gravitational pull.



This mosaic of several NASA Chandra images shows the central region of our Milky Way galaxy glowing in X-ray light, far more energetic than the visible light our eyes can detect. The bright sources seen here are from million-degree gas falling onto the multitude of black holes and neutron stars that fill the galaxy.

The Black Hole Finder Probe will conduct a census of hidden black holes, revealing where, when, and how they form.

An artists concept of a black hole surrounded by hot, X-ray-emitting gases (shown in blue) swirling towards the void.

Einstein Inflation Probe

How did the Universe begin?

The Big Bang theory states that matter, space, and time (as we know it) were created about 13.8 billion years ago. It took only seconds after the Big Bang for atomic particles to form yet hundreds of millions of years for stars and galaxies to appear. The details of the Big Bang after about one second to the present are well understood. What happened in the first fraction of a second, however, is the greater mystery. Understanding what occurred just after the Big Bang will allow us to answer the question of what caused the Big Bang. Scientists suspect that there was a split-second period of rapid expansion, called inflation, which enabled stars to form and life to exist.

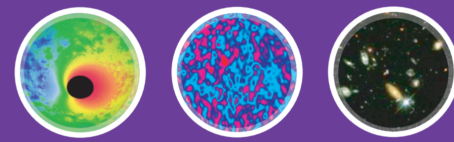
Wouldn't it be nice to look back in time to the moment of its creation to see what happened? That's our plan. We can study the Big Bang today through observations of its afterglow, called the cosmic microwave background. This ancient, remnant radiation is all around us and, in fact, makes up a significant fraction of the static seen on any "in-between" channel on your television.

A journey back in time…

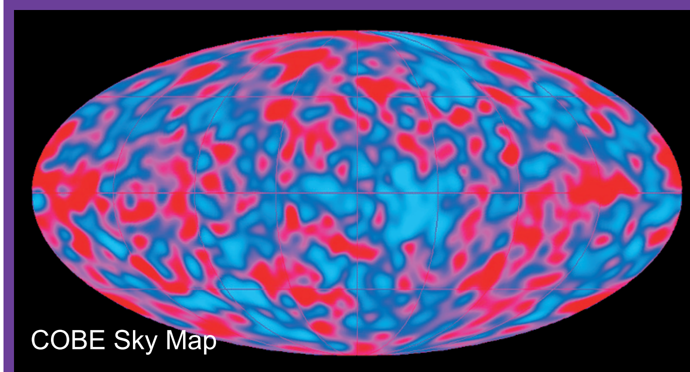
During the last decade, sky maps of this remnant light—first from NASA's Cosmic Background Explorer (COBE) satellite and more recently from other experiments, including Antarctic balloon flights and NASA's Wilkinson Microwave Anisotropy Probe (WMAP)—have displayed wrinkles imprinted on the Universe in its first moments. These maps reveal slight temperature variations on the sky—a little warmer here, a little colder there—that point back to density differences within one second of the Big Bang—a little more matter here, a little less matter there. Regions with higher density attracted more matter, forming galaxies over the course of hundreds of millions of years.

Understanding what caused that initial lumpiness will point us to what powered the Big Bang. We need to probe a little deeper, though. Modern theoretical ideas predict that the wrinkles COBE discovered arose from two kinds of primordial particles: from the energy field that powered the Big Bang; and from gravitons, fundamental particles of space and time. One theory related to this is called inflation, which states that at 10^{-35} second into the Big Bang, the visible Universe expanded far faster than the speed of light, growing from an atomic size to about a grapefruit size in less than a thousandth of a second. The rapid expansion amplified density differences. Without inflation, the Universe would be featureless—no stars, no galaxies, no voids of seemingly empty space.

This is the point in time we plan to visit with an "inflation" space probe. One proposed approach for the Beyond Einstein inflation probe would study the polarization of the cosmic microwave background, similar to how WMAP is so carefully measuring temperature patterns today. Patterns in the polarization will reveal if and how inflation stretched the Universe. Another approach would be through the study of galaxy evolution, for the large-scale distribution of matter today can reveal the physics that drove inflation.

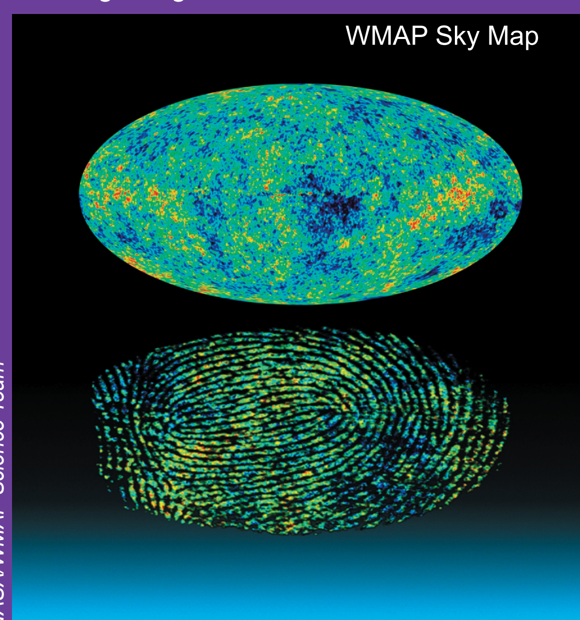


"How did the Universe begin?" Scientists believe the Universe began with a period of "inflation," when the Universe expanded so rapidly that parts of it separated from other parts faster than the speed of light. The rapid expansion enabled slight density differences to ultimately grow into the stars, galaxies, and vast voids we see today. Yet what propelled this inflation? The Einstein Inflation Probe will investigate.



COBE Sky Map

All-sky maps of the afterglow of the Big Bang—from NASA's Cosmic Background Explorer, or COBE (above), and more recently from the Wilkinson Microwave Anisotropy Probe, or WMAP (below)—reveal slight wrinkles in the otherwise smooth blanket of radiation. The wrinkles are temperature variations that, like a fingerprint, contain very specific information about how the Big Bang occured.



WMAP Sky Map

NASA/WMAP Science Team